Technical Bulletin of the Louisiana Wild Life and Fisheries Commission

Rockefeller Refuge Levee Study

Refuge Division
New Orleans, Louisiana
1959

Louisiana

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Technical Report of the Louisiana Wild Life and Fisheries Commission

Rockefeller Refuge Levee Study

By

LEWIS G. NICHOLS

Refuge Division

New Orleans, Louisiana

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Foreword

Louisiana has over 4,000,000 acres of marsh land. A large portion of this marsh is capable of greater productiveness through water controlled by levees. The realization that a need exists for a clearer understanding of the behavior of artificial levees placed on marsh served as the incentive for this study. The Rockefeller Refuge Expansion Program provided the rare opportunity for: (1) Thorough study of the undisturbed marsh prior to levee construction; (2) Construction of levees under controlled conditions; and (3) Constant surveillance of the levees during the post-construction period.

The primary objective of this study is to establish relationships between the various types of marsh and the action of levees placed on these same marsh types. As a result of this research, predictions of levee loss for newly constructed marsh levees are presented. These predictions are derived from observation of actual levees and the application of basic soil mechanics principles. A secondary and more fundamental aim of this report is to provide answers to a few of the questions frequently asked in marsh improvement programs.

TED O'NEIL, *Chief*
Fur Division

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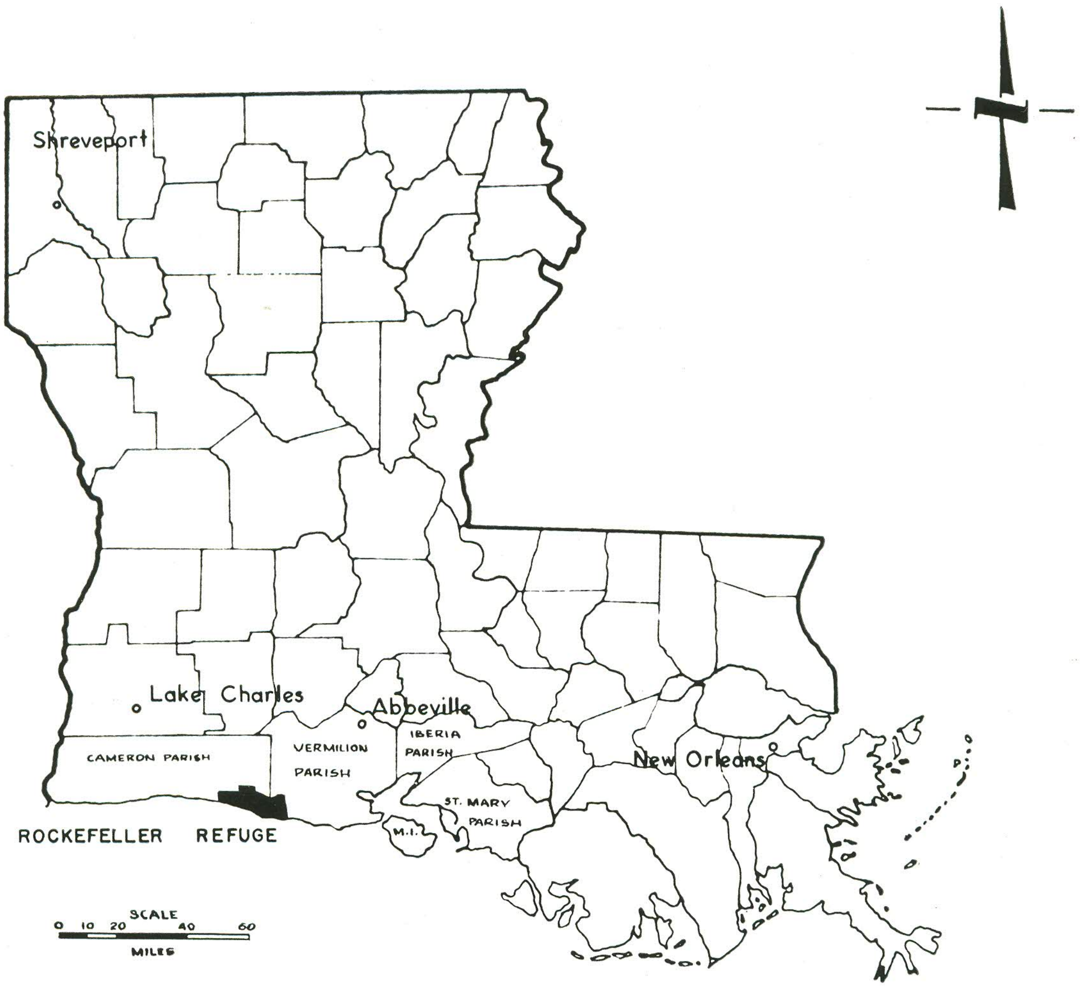

INDEX MAP OF LOUISIANA

SHOWING LOCATION OF ROCKEFELLER REFUGE

PLATE I

Rockefeller Refuge Levee Study

INTRODUCTION

In the past few years the increased tempo of oil exploration, coupled with the use of the coastal marshes for inland waterways, has introduced additional water control problems to the marshland property owner. It has become necessary to maintain canal levees and construct new ones to improve the marsh or return it to its previous ecological position. The success of such a venture is largely dependent upon a sound levee system. Marshland levees must be constructed to maintain an effective height and width for a great number of years. To achieve this, careful consideration must be given to the problem of levee subsidence and shrinkage. The expansion program in progress on Rockefeller Refuge presents a good starting point for a study of levees constructed on marsh. The Refuge provides old levees for comparison and new levees for a thorough study of levee changes through time.

The difficulty encountered in building marsh levees stems from the unstable condition of the marsh itself. Normally the levee must be composed of the soft almost fluid marsh material and also depend upon this same substance for its foundation. Therein lies the crux of the problem. First, the weight of the levee causes it to sink into the soft marsh. Adjustments to this levee overburden continue for many years. Second, the high moisture content of the marsh material controls the initial height to which the levee may be constructed and is an indication of the amount of shrinkage.

In dealing with earthwork in the marsh every statement and conclusion pertaining to reactions of the marsh soils to overburdens involves many variables. The best method for marsh earthwork

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Mr. H. A. Huesmann, Soils Division, Corps of Engineers, U. S. Army, New Orleans District, discussed this problem with the writer and gave many valuable suggestions. Mr. H. L. Lehmann, Testing and Research Engineer of the Louisiana Department of Highways assisted in the analysis of the soil samples. Mr. David E. Butler did the final drafting of the plates.

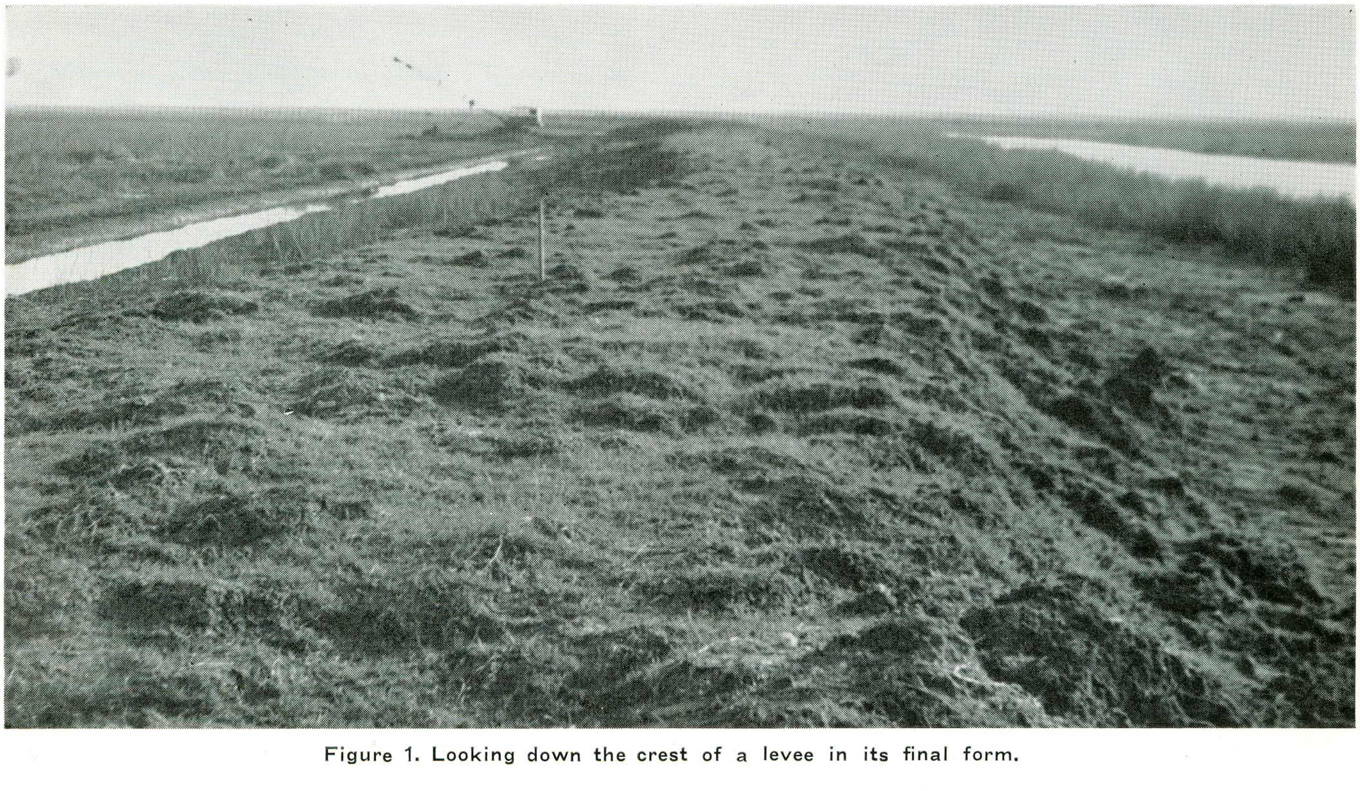


Figure 1. Looking down the crest of a levee in its final form.

and correspondingly a study of levee construction and permanency is based on an observational procedure. The study must begin with the initial construction and then through observation the various reactions to marsh conditions may be detected as they occur, and correctly evaluated. Frequently detailed field work of boring and sampling, and laboratory testing produce results that leave much room for interpretation. A knowledge of marsh subsoil conditions is always incomplete and uncertainties inevitably enter into any calculation and prediction.

As might be indicated by the above statements this paper is divided into parts separated on the basis of observation and theory. The first part deals with results obtained through field work and direct observation. The second part is based on theoretical computations in which values obtained from laboratory tests of field samples are inserted in formulas and the results interpreted. The third part combines knowledge gained from direct observation and theory and predicts levee loss in various types of marsh soil.

ANALYSIS OF ACTUAL LEVEE SUBSIDENCE AND SHRINKAGE

Field Methods. The field work for this study consisted of precise cross sections of the levees and detailed borings of adjacent undisturbed marsh. Samples collected from each borehole were described and tested for moisture content. In addition, the Research and Testing Division of the Louisiana Department of Highways conducted complete soil analysis tests on selected samples. The various horizons or contacts in the marsh and under the levee were correlated. From these correlations the amount of subsidence and compression of each individual stratum within the marsh was determined. In this phase of the study the differential of moisture contents be-

Figure 2. Profiling a levee. Levee is 5 feet high and has been dressed by a dragline working from mats on the berm. Note damage to berm, in foreground of photograph.

tween undisturbed marsh and the levee was used to estimate loss from shrinkage. The loss of levee to erosion was included in the shrinkage measurements.

Discussion. Subsidence and shrinkage are the major causes of levee loss. Separating the loss into its component causes frequently can not be accomplished, especially after a levee has been in place for several months. Therefore, periodic levee cross sections instigated upon completion of the levee are the only means of establishing accurate rates of levee loss. Although this does not divide the loss into subsidence and shrinkage, it does give an insight into how levee loss progresses in time. Subsidence accounts for the greater part of the early loss and can be measured. Shrinkage takes place above ground and can be noted as the levee size diminishes. However, subsidence is reflected here also and to assign respective values on the basis of observation is impossible. A good rule when calculating shrinkage loss is that it will be completed in one good drying year.

In this study, 21 levee cross sections are used in making comparisons, establishing relationships, and drawing conclusions. In addition, levee profiles taken by field parties of the Louisiana Department of Public Works and the Engineering Office of the Louisiana Wild Life and Fisheries Commission were studied. Plate II shows the locations of the levee cross sections. Table 1 lists the cross sections along with the age of the levee, the thickness of the organic layer, the subsidence at the time of the cross section, and the total predicted subsidence based on theory.

The various moisture contents of the marsh strata and physical conditions of these strata control the per cent of levee loss. A soft fresh marsh, a slight marsh ridge,[1] or a firm salt marsh will each have their individual problems. Plate III shows a levee placed on a soft, almost fluid marsh. This levee was constructed in two lifts, two months apart. As shown here, three months after the first lift, almost 40 per cent of the levee is below the marsh surface, mostly in the organic layer. This levee will lose still more height and volume to shrinkage as indicated by the high moisture content of the levee. It will also continue to subside, principally in the clay layers, for many years to come. In contrast to Plate III, Plate IV shows a levee the same age and put up in one lift. This levee differs in that it is located on a marsh ridge and consequently is composed of firm marsh ridge material. The organic layer is very thin here and there is very little immediate subsidence, only nine per cent of the levee is below the marsh surface. This levee will continue to subside but the marsh ridge does not have a large quantity of

TABLE 1.

LEVEE CROSS SECTIONS INCLUDING THE SUBSIDENCE AT THE DATE OF SECTIONING AND THE PREDICTED SUBSIDENCE BASED ON THEORETICAL COMPUTATIONS

Levee Cross Section	Number and Location	Age of Levee	Thickness of Organic Layer in Feet	Subsidence to Date in Feet	Predicted Subsidence in Feet[3]
1a	Headquarters Canal (east)[2]	1 mo.	1.0	0.5	1.8
1b	Headquarters Canal (east)[2]	5 mo.	1.0	0.6	1.8
1c	Headquarters Canal (east)[2] (levee raised 2 feet)	12 mo.	1.0	1.1	2.0
2a	Headquarters Canal (west)[2]	1 mo.	0.75	0.6	1.1
2b	Headquarters Canal (west)[2]	12 mo.	0.75	1.0	1.1
3	Humble Canal (north) (raised 12 mo. ago)	13 yrs.	1.6	1.2	2.3
4	Humble Canal (south) (raised 12 mo. ago)	13 yrs.	2.5	1.7	2.6
5a	Union Producing Canal	12 mo.	1.6	2.0	2.3
5b	Union Producing Canal (levee raised 2 feet)	21 mo.	1.6	2.1	2.5
6	Superior Canal (north)[2]	36 mo.	1.7	0.6	1.4
7	Superior Canal (south)	1 mo.	2.5	1.7	2.7
9	South Canal Lakes 2 & 3 (west)[2]	3 mo.	0.5	0.3	1.1
10	Lake 8 Canal[2]	1 wk.	1.8	0.5	1.6
11a	North Island Canal (south)	1 wk.	2.3	1.0	2.4
11b	North Island Canal (south)	5 wks.	2.3	1.8	2.4
12	Bertrand's Canal	3 mo.	2.4	2.0	2.6
13	North Island Canal (north)	1 wk.	2.5	0.6	1.9
14	Lake 10 Canal	1 mo.	1.4	0.6	1.2
15	Boundary Line Canal	10 mo.	1.6	0.9	1.6
16	South Canal Lakes 2 & 3 (east)	3 mo.	2.4	1.1	2.5
17	South Canal Lakes 2 & 3 (east)	3 mo.	2.4	1.2	2.5

NOTE: Initial thickness of all levees is approximately 6 feet.

[2]Denotes "ridge levee".

[3]This amount of subsidence will not be realized for many years. This figure does not include levee loss due to shrinkage. Maximum shrinkage is normally attained after one year, therefore as the levee ages a proportionate amount of shrinkage is included.

[1]The term, marsh ridge, as used here is a narrow, linear, strip of marsh paralleling the gulf shoreline. It is slightly higher and firmer than the surrounding marsh. Marsh ridges are discontinuous and variable as to height (average—0.3 foot) above the marsh, thickness (average—4 feet), and width (average—300 feet).

For a complete discussion of marsh ridges see Nichols, Lewis G., "Geology of Rockefeller Wild Life Refuge and Game Preserve, Cameron and Vermilion Parishes, Louisiana", Louisiana Wild Life and Fisheries Commission.

moisture to lose and thus will resist compression. In addition the overburden of the levee will be equally distributed throughout the lower layers thereby reducing compression.

Plate V is of a levee placed in marsh denuded by saltwater burn.[4] After one month, 12 per cent of this levee was below the marsh surface. After five months, additional subsidence was imperceptible. After 11.5 months, the levee was reshaped and raised two feet, with no additional material added. Two weeks later, the levee was cross sectioned again and Plate VI shows the results. Now 24 per cent of the levee is below the marsh surface and the lower strata, even the shiny gray clay, are beginning to reflect compression. Moisture content of the levee indicates that maximum shrinkage has not yet been realized.

A definite relationship exists between the moisture content of the marsh and subsidence. Graph a of Plate VII compares moisture content of the marsh strata, *i. e.*, the material that will make up the levee and also be the foundation, and the per cent of levee loss from subsidence. The thickness of the surface organic layer at each levee site is also depicted. This graph effectively illustrates the difference in subsidence between ridge levees and non-ridge levees, the former constructed on marsh ridges and the latter, on normal marsh. The ridge levees have a regular increase of subsidence as the moisture content increases. This moisture increase is explained by the increase in thickness of the organic layer. The non-ridge levees show irregular results, primarily because the organic layer is thick and correspondingly the moisture content is high with a net result of greater subsidence. Graph b of Plate VII compares the total loss of levee which includes both subsidence and shrinkage with the thickness of the surface organic layer. As the organic layer increases from 0 to 2 feet in thickness the levee loss is regular and reaches a loss of 25 per cent. Increases in organic matter thickness beyond two feet result in greatly increased levee loss.

The relationship of total levee loss with time is represented by the graph of Plate VIII. Here the losses are separated into subsidence loss and shrinkage loss. The subsidence loss in the organic layer takes place immediately, within the first few weeks as is indicated by the large amount of early levee loss. Shrinkage loss, based on moisture differential of levee and marsh, is nearly complete at the end of the first year. After the first year levee loss occurs at a very slow and constant rate. This latter loss is almost entirely caused by compression of the clay layers. In this relationship the ridge levees separate themselves from the non-ridge levees on per cent loss of levee. The curves are similar with the non-ridge levees averaging 20 per cent more levee loss. This loss is explained in the higher moisture content of the non-ridge levees which accounts for the greater subsidence and the greater shrinkage. It should be emphasized that after three years levee loss will continue to be noted, but only in a very small amount.

ANALYSIS OF THEORETICAL CONSIDERATIONS

THEORY.[5] The science of soil mechanics came into being out of necessity. Problems involving soil assumed many facets and science met the challenge with new tools. Yet in dealing with soil there are many indeterminate qualities and the methods provided by the soil scientists are frequently inadequate. Highly refined methods of sampling and testing used in conjunction with complicated formulas are useless if the soil strata are not homogenous and continuous in horizontal directions. Such is the case when dealing with marsh soil. However, it is necessary to rely upon theoretical applications in that they point the way and set the limits, for without them we would have to depend upon experimentation alone.

The soil property that we are concerned with is porosity. Porosity is the ratio of the volume of voids to the total volume of the soil aggregate. The term, volume of voids, refers to that portion of the volume of the soil not occupied by mineral grains. The void ratio e is the ratio of the volume of voids to the volume of the solid substance. The void ratio is important in computing the amount of compression a stratum is capable of under-

[4] The intrusion of salty gulf water into a brackish to freshwater marsh will kill all existing vegetation. Prior to the introduction of saltwater tolerant plants, an area denuded by saltwater burn is essentially a bare mudflat.

[5] A complete discussion of the theoretical principles presented may be found in: *Soil Mechanics in Engineering Practice* by Karl Terzaghi and Ralph B. Peck published by John Wiley and Sons, Inc. 1948.

going. By finding the compressibility of a soil stratum brought about by a known overburden the subsidence of a levee can be computed. The void ratio is also useful in finding the maximum shrinkage that a soil, or in this case, a levee will undergo.

Plate IX shows the relationships between the water contents and void ratios of the various strata of a non-ridge marsh and a marsh ridge area. The physical descriptions of the marsh strata should be compared with the respective water contents in per cent wet weight, water contents per cent dry weight, and the corresponding void ratios. These relationships are vital in compression computations.

A graph based on the compressibility of confined clay layers with a known overburden is presented on Plate X. Three curves are plotted, curve A is computed for a levee four feet high, curve B is for a levee six feet high, and curve C is for a levee eight feet high or a levee six feet high later raised two feet. These curves give the compression expected for soft organic clay layers up to 35 feet thick. Plate XI gives similar compression values for marsh ridges.

The curves are plotted for values obtained from the formula:

$$S = H \frac{Cc}{1+e_0} \log \frac{P_0 + \Delta P}{P_0}$$

In this formula S is the amount of compression, H is the thickness of the compressible layer, Cc is the compression index of the compressible layer, e_0 is the original void ratio of the compressible layer, P_0 is the initial pressure or the natural overburden pressure of the compressible layer, and ΔP is the consolidation stress brought to bear by the levee. The compression index was derived for soft organic clay by using the formula $Cc = 0.009(Lw - 10\%)$. Values for Lw or the liquid limit were determined from soil tests conducted by the Testing and Research Section of the Louisiana Department of Highways. P_0 and ΔP were computed from formulas using the specific gravity of the soil and its water content in per cent dry weight. The value used for the specific gravity of the clay is the statistical average for clays which is approximately 2.7. The actual specific gravity of very organic clays is considerably lower than for inorganic clays, but the differences in this instance are slight and will cancel each other out in the overall clay thickness.

The formula used for computing the shrinkage of a levee is based on the void ratio and is $C = H\left(\frac{e_1 - e_2}{1+e_1}\right)$. In this formula C is compaction or shrinkage, H is the thickness of the layer or levee, e_1 is the original void ratio, and e_2 is the final void ratio. Using the above formula the average loss of height by shrinkage for a levee six feet high would be 1.65 feet. For a levee four feet high, the loss of height would be 1.10 feet. These values were computed by using average moisture contents for a levee in place over two years to compute the final void ratio, and average moisture contents for a newly constructed levee to compute the original void ratio. Therefore the above shrinkage figures apply to a levee after some shrinkage has already taken place during and immediately after the process of construction.

USE OF GRAPHS IN PREDICTING LEVEE LOSS

The main objective of this levee study is to gain an understanding of levee behavior on marsh. A corrollary of this objective is to develop a key for predicting how much a levee will subside and shrink under various conditions encountered, thus being able to forecast if it will be practical to construct a levee and if so how much maintenance will be required. To accomplish this, it is necessary to combine fact with theory. Results derived from this union have heritable limitations yet even an approximate prediction may be all that is necessary in a virgin area.

The diversified nature of marsh strata and the difficulty in obtaining representative samples have imposed restrictions on a key to levee loss. Therefore the subsidence loss is separated into two composite marsh strata groups and levee shrinkage into one average figure. The surface organic layer is the first marsh composite. The compression figures for this layer are based on actual results obtained from levee cross sections. Plate XII contains this graph. The second compression phase is that which takes place in the soft organic clay. This clay may be gray-black, or shiny gray. It also may have thin silt and sand lamina but these are considered as negligible in the overall compression. Plate X contains this graph. If the proposed levee is on a marsh ridge the subsidence may be computed by using the graph on Plate XI. The only information needed to use these graphs is the thickness of the organic layer, the thickness of the soft organic clay, or the thickness of the firm marsh ridge material.

To assist in illustrating the use of the graphs, Table 2 contains predictions of levee loss for four levees in which the initial height is known. For the Lake 8 Canal marsh ridge levee the predictions are arrived at as follows. The organic layer is 1.8 feet thick. Using the Plate XII graph, the predicted compression for an organic layer 1.8 feet thick and a levee six feet high is 0.9 foot. At the Lake 8 Canal levee location the ridge is four feet thick and expected compression as found on the Plate XI graph is 0.7 foot. The total predicted levee subsidence is 1.6 feet. The soft organic clay layer beneath the marsh ridge will also compress slightly but this is considered negligible for this size marsh ridge and levee. The predicted shrinkage for this levee is based on actual moisture contents and is 1.6 feet. Thus the total levee loss in height is 3.2 feet, giving a final levee height of 3.9 feet. At the North Island Canal (south) levee the organic layer is 2.3 feet thick and the soft organic clay is 22 feet thick. By using Plates XII and X respectively the compression is 1.2 feet and 1.2 feet. The shrinkage prediction for this levee based on actual moisture content measurements is 1.1 feet. The final levee loss is 3.5 feet and the predicted final levee height is 2.9 feet.

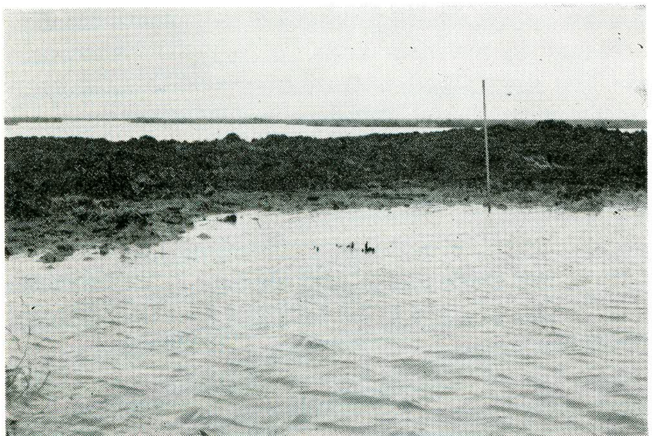


Figure 3. Levee across shallow marsh lake. The fluid nature of the levee material causes the levee to spread rather than maintain its intended shape.

TABLE 2.
FOUR LEVEE CROSS SECTIONS WITH THEIR INITIAL HEIGHT AND THE PREDICTED RESULTANT HEIGHT AFTER MAXIMUM SUBSIDENCE AND SHRINKAGE

Levee Cross Section	Number and Location	Initial Levee Height in Feet[7]	Predicted Subsidence in Feet	Predicted Shrinkage in Feet	Resultant Levee Height in Feet[8]
10	Lake 8 Canal[6]	7.1	1.6	1.6	3.9
11a	North Island Canal (south)	6.4	2.4	1.1	2.9
13	North Island Canal (north)[6]	7.6	1.9	1.4	4.3
14	Lake 10 Canal[6]	7.4	1.2	1.5	4.6

As stated earlier the average shrinkage for a levee six feet high is 1.65 feet and for a levee four feet high, 1.1 feet. In lieu of actual moisture contents these figures should be used. Maximum shrinkage takes place in from one to two years. The time required for the subsidence to reach its maximum figure has not been determined. Subsidence takes place as the moisture is slowly compressed out of the confined layers beneath the levee. In layers beyond a few feet in depth compression is a very slow process. Even after 10 years, subsidence has been observed in levees.

It will be noted that the above graphs apply to the relatively simple marsh sequences of organic matter and clay. Natural levees and sand and shell strata are not considered. When these beds are present in appreciable thickness they serve as good foundation and subside very little. In the subsurface they also serve to dampen subsidence. Clay and organic matter are the main causes of levee loss in marsh.

CONCLUSIONS

1. Levee loss can be predicted, within certain limits, for levees constructed on unstable marshlands. Test boreholes provide the information for these predictions.

[6] Denotes "ridge levee"
[7] Includes initial subsidence
[8] Height is above mean gulf level. Marsh elevation ranges from below gulf level to 1.5 feet above, the average is +1.0 foot.

Figure 4. Cracked and blocky surface of dressed levee showing an advanced stage of drying.

Figure. 5. Levee placed on soft, marshhay cordgrass marsh. The levee is well formed thus showing an advantage of a heavily grassed marsh. This levee has been in place one month and has lost approximately 1/3 of its original height.

2. The paramount factor in the permanence of a levee is the type of marsh upon which the levee is placed. Two complementary facts are immediately apparent, namely the more fluid the marsh, *i. e.*, the higher the moisture content, the less weight it will support, and correspondingly the less solid material available to make up the final levee.

3. The condition of the marsh at the time the levee is placed is of great importance. During dry periods when there is no water on the marsh, the moisture content of the near surface material is low. This results in greater strength in the top two feet of the marsh. Equally important is the better formed and higher levee that results from their drier and more compact material. When water is over the marsh, the surface material is supersaturated and becomes very weak and almost fluid. Poorly shaped levees which spread across the marsh result from this condition.

4. The thickness of the surface organic layer controls the amount of immediate subsidence. This layer compresses to approximately 60 per cent of its original thickness. The compression is readily explained in that the organic layer is made up almost entirely of water and root material.

5. The soft clay layers compress more slowly. Levees in place over two years and six feet high show 0.6 foot of subsidence into this material.

6. Moisture content increases with the amount of organic matter present and is a reliable key to subsidence and shrinkage.

7. Maximum shrinkage takes place in one good drying year.

8. Marsh material is normally saturated with water and dries very slowly. A crust forms on exposed surfaces of the levee. This crust soon crumbles and disintegrates allowing deeper drying as cracks form in the levee surface. Capillary action brings water from the water table into the levee and maintains a high moisture content. Only in extended dry periods may the water table be expected to lower enough for deep drying to occur in the levee.

9. Erosional loss in clay levees due to surface drying will be relatively minor provided vegetation is introduced. In sandy levees, erosion could be a serious problem if soil binding plants are not encouraged.

10. Thick marsh vegetation provides some surface strength. However, if this vegetation hides soft organic layers, the predicted compression for the soft organic layer will be realized.

Appendix

STATEMENTS PERTAINING TO LEVEE CONSTRUCTION AND MAINTENANCE

1. **Drag bucket versus clam bucket.** There is no difference between levees constructed by these two methods. The soil aggregate and final moisture content will be the same regardless of the method of disturbance after the soil densities re-establish an equilibrium. Initial unnatural pressures may be introduced by improper placement of the levee material.

2. **Mat damage to the berm of a canal levee.** When the marsh is so unstable that it becomes necessary to dig from double mats, the berm will be damaged. The natural resiliency of the marsh is destroyed and grooves left by the runner mats will remain in the berm. These grooves contain water and weaken the berm. Marsh firm enough to support a dragline on single mats will not be compressed enough to lose its natural resiliency or kill the vegetation.

In extremely unstable marsh it is advisable to dig from a spud barge. In order to give the levee a protective berm in this type marsh it may be necessary to first construct an artificial berm and then place the levee behind it.

Figure 6. Raising and reshaping levee while working from mats on the levee crest. A drag bucket is used here.

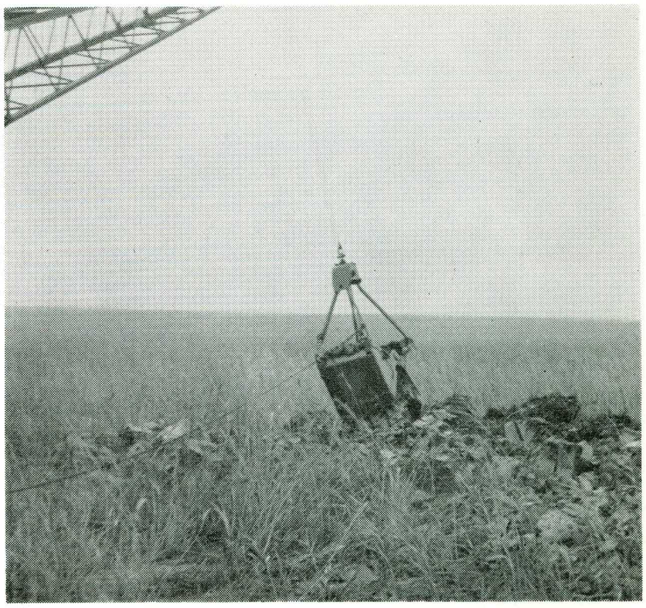


Figure 7. Building a levee with a 4 yard clam bucket. This is firm marsh and the levee stands over six feet high. Note the material being placed rather than dropped.

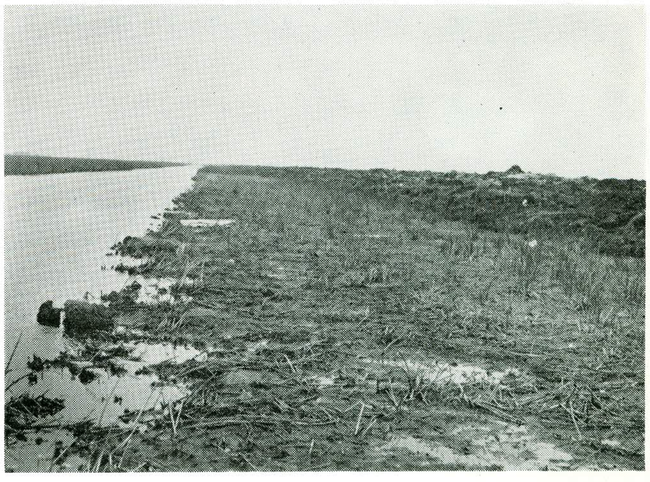


Figure 8. Undamaged berm of a canal dug by a dragline mounted on a spud barge. Marsh is firm and the result is a high and well formed levee.

3. **One lift versus two lifts.** The softer the marsh the more lifts necessary to construct a levee of normal height. When the maximum angle of repose is reached for the marsh material used, further adding of material will only serve to widen the levee. If the proposed initial height is reached at this stage then the one lift has accomplished as much as can be done with the raw marsh material. Nevertheless at this point the levee should be allowed to subside and shrink for one drying season. Then if additional height is needed, a second lift added. When required to construct a levee to a specified height in a short length of time, marsh conditions may make it necessary to make a second lift within a few weeks. The value of this practice is in reaching the specified

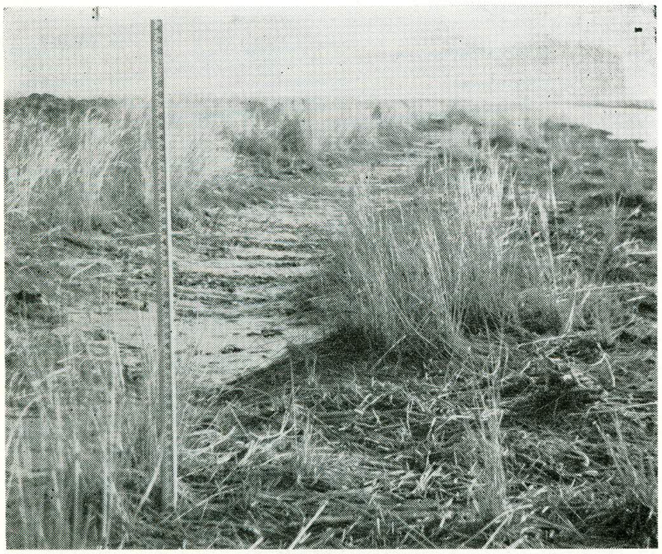


Figure 9. Damaged berm. The trough or groove at the toe of the levee was caused by runner mats. If double matting is required when digging from the berm, this type damage results.

Figure 10. Spud barge mounted dragline digging canal with 4 yard clam bucket. This is the type equipment most practical for levee construction in soft marsh.

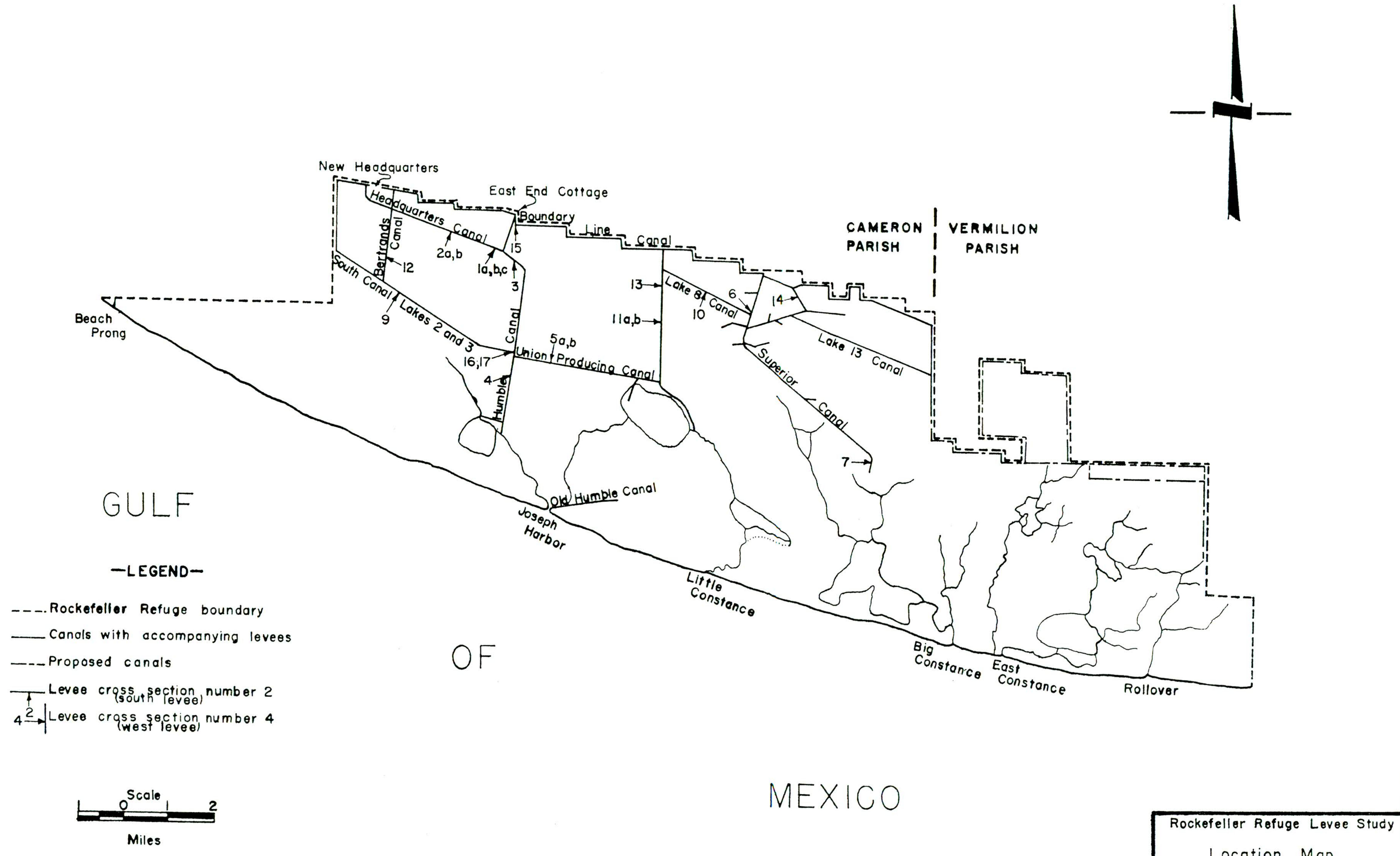
Figure 11. Undressed levee constructed from firm marsh material and fine sand and shell. Levee is near Grand Chenier-Pecan Island beach ridge complex.

initial height in hopes that the final height, after subsidence and shrinkage, will be sufficient. Under normal marsh conditions no attempt should be made to construct a levee higher than six feet.

4. **Raising and reshaping a levee.** If possible this should not be done until initial subsidence and maximum shrinkage have been realized. This normally takes from one to two years depending upon the drying conditions. Frequently one good drying year will suffice. The benefit derived in waiting for the maximum shrinkage is in being able to accurately foresee future subsidence based on the new levee height and plan accordingly.

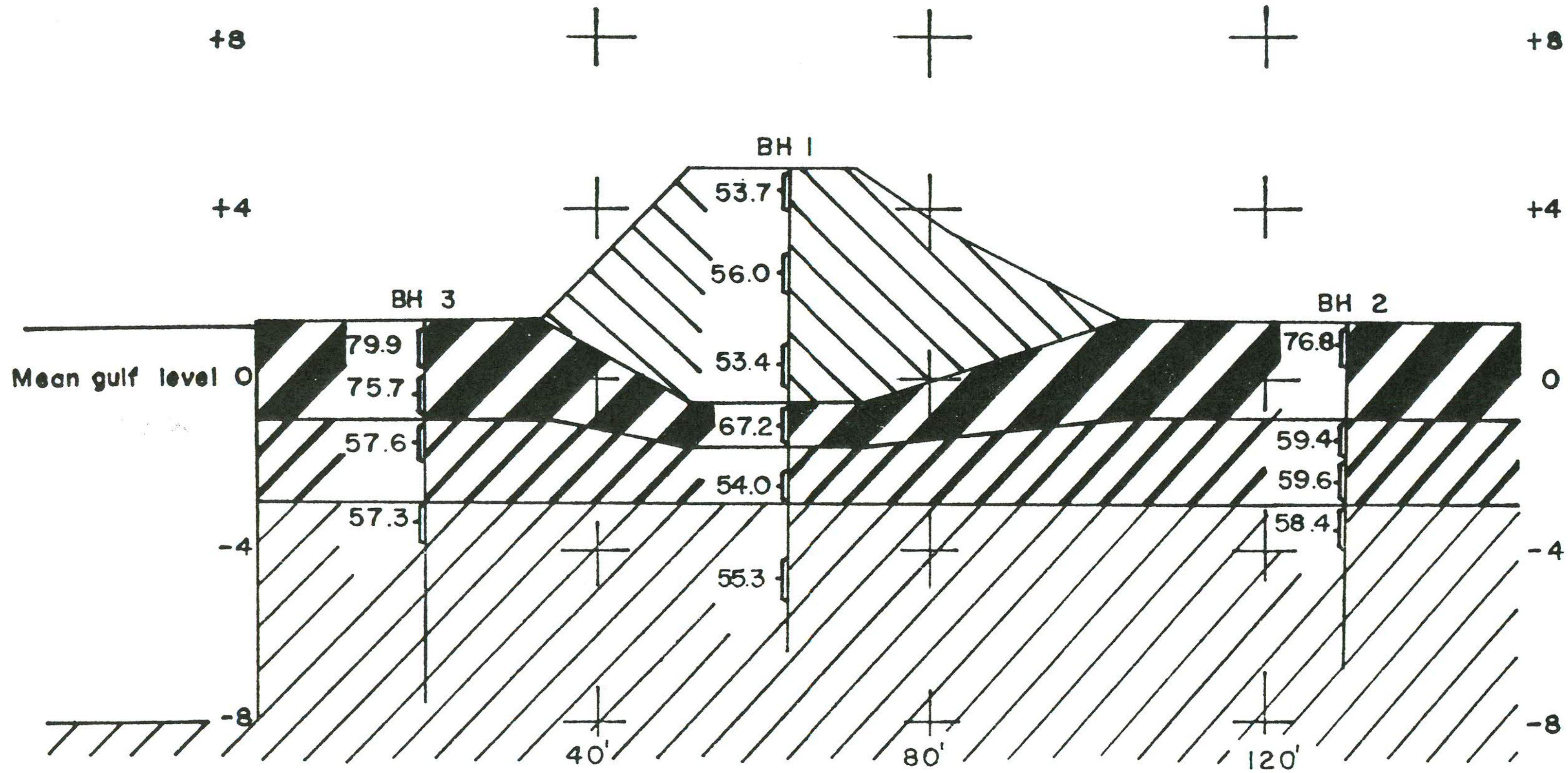
Here it is especially important not to raise a levee higher than six feet above the marsh surface. Marsh levees as such do not have sufficient strength within themselves to support a greater height. Under heavy loads the levee will rupture and slide along shear planes established between the dry crust and the moist inner portion of the levee.

Figure 12. Raised and reshaped levee immediately aftercompletion.



Rockefeller Refuge Levee Study

Location Map
for
Levee Cross Sections



Levee Cross Section No.12 (non-ridge) Bertrand's Canal Lake 3 (east levee)

Horizontal scale 1 inch=20 feet Vertical scale 1 inch=4 feet

Datum plane is mean gulf level

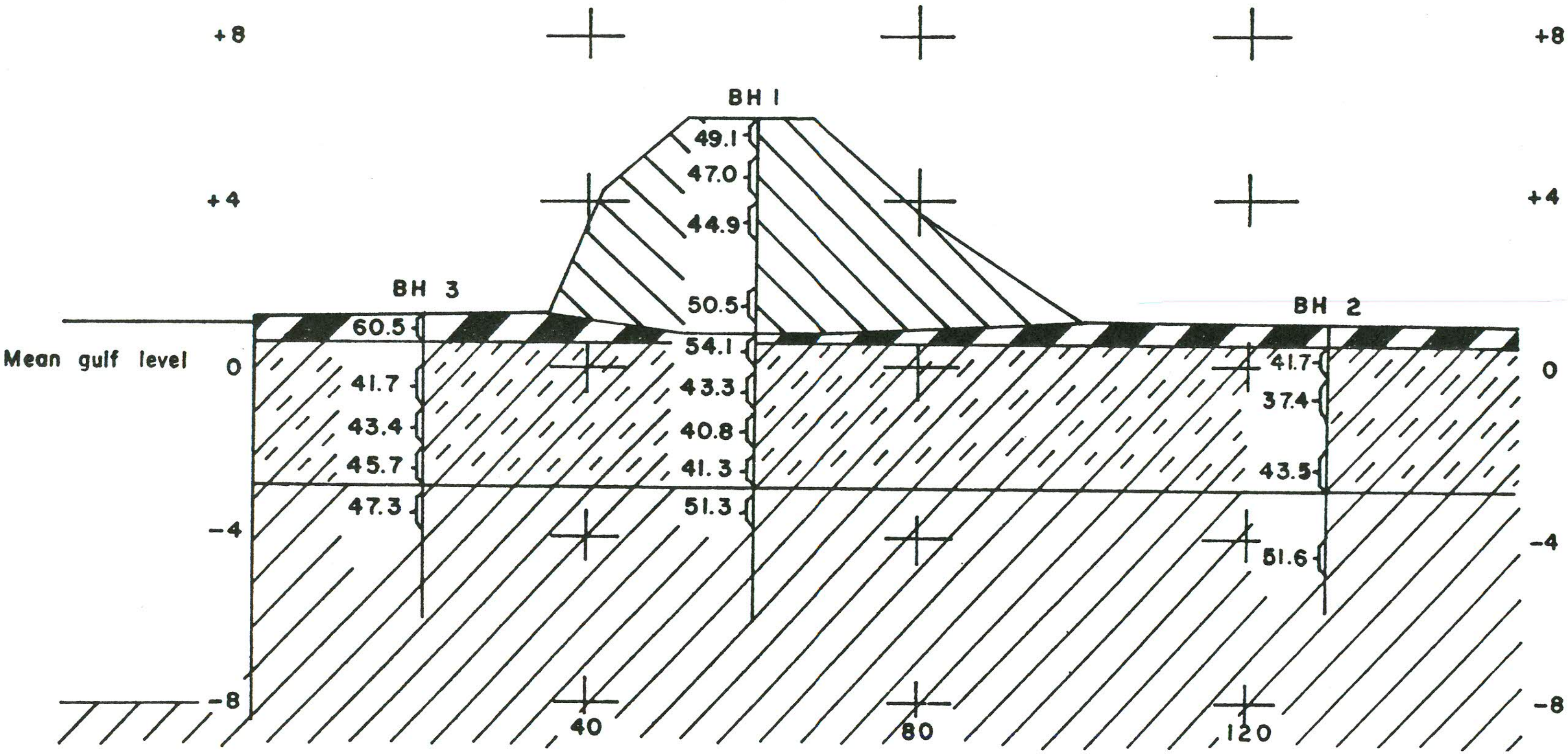
Numbers adjacent to bore holes are moisture contents in percent wet weight

Date of section June 21, 1955

Rockefeller Refuge Levee Study

Levee Cross Section No. 12

For location see PLATE II



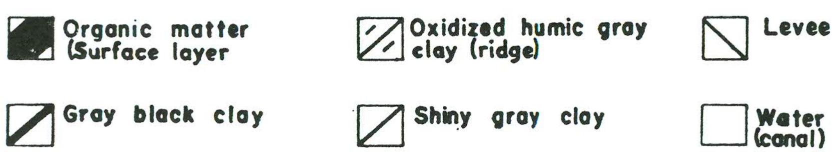
Levee Cross Section No. 9 (ridge) South Canal Lakes 2 and 3 (south levee)

Horizontal scale 1 inch=20 feet Vertical scale 1 inch= 4 feet

Datum plane is mean gulf level

Numbers adjacent to boreholes are moisture contents in percent wet weight

Date of section June 16, 1955

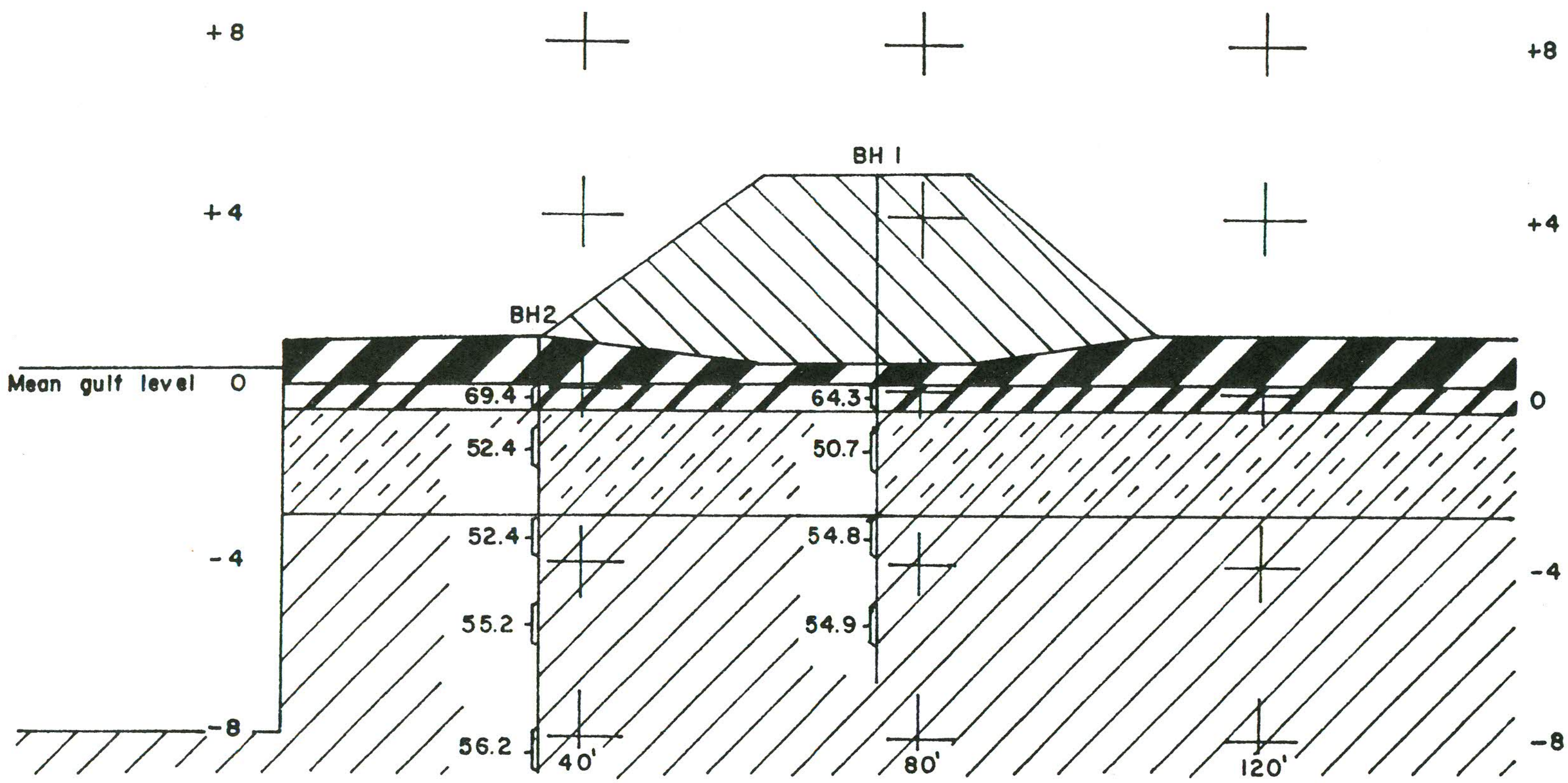


For location see PLATE II

Rockerfeller Refuge Levee Study

Levee Cross Section No. 9

PLATE IV



Levee Cross Section No. Ia Headquarters Canal (south levee)

Horizontal scale 1 inch=20 feet   Vertical scale 1 inch=4 feet
Datum plane is mean gulf level
Numbers adjacent to boreholes are moisture contents in percent wet weight
Date of section September 13, 1954

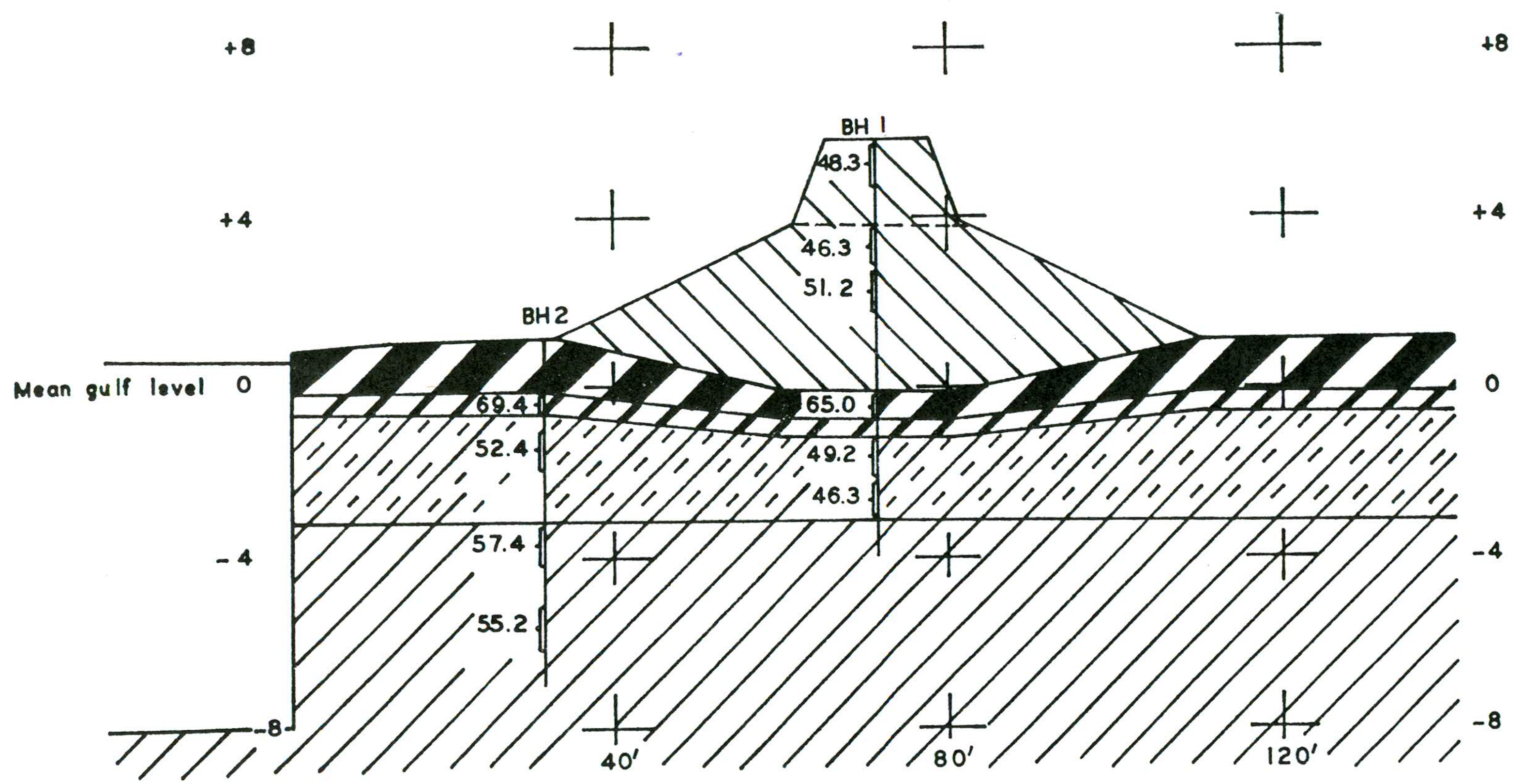
For location see PLATE II

Rockefeller Refuge Levee Study

Levee Cross Section No. Ia

PLATE V

841-B



Levee Cross Section No.Ic Headquarters Canal (south levee) resectioned

Horizontal scale I inch=20 feet Vertical scale I inch=4 feet

Datum plane is mean gulf level

Numbers adjacent to boreholes are moisture contents in percent wet weight

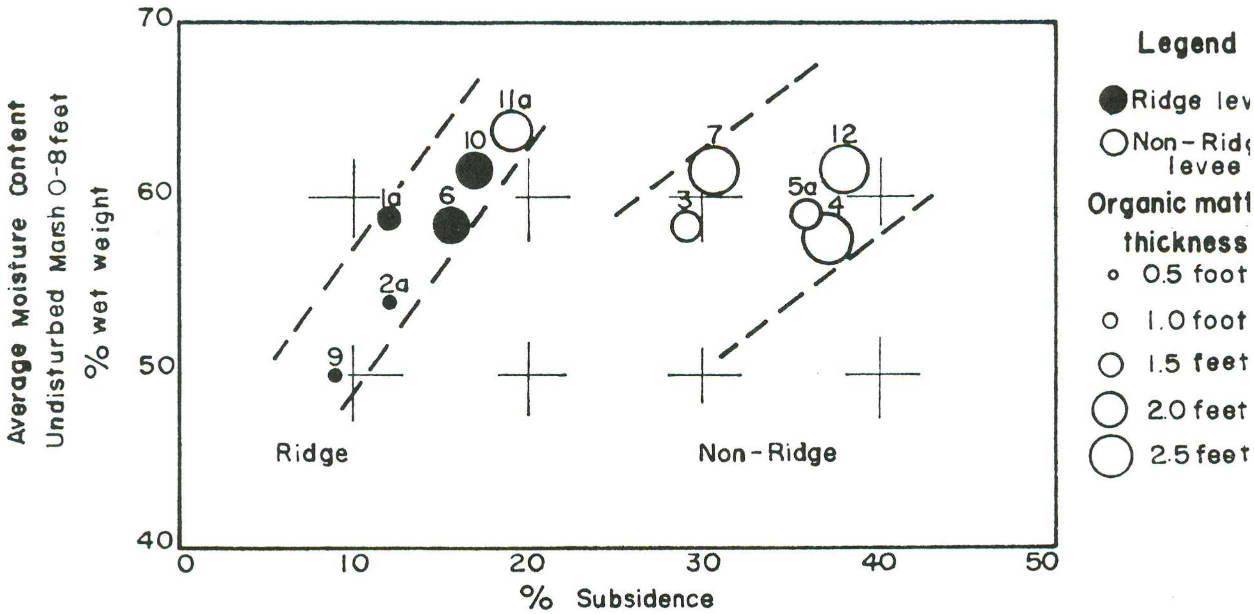
Date of section August 9, 1955

Levee reshaped and raised 2 feet ; for location see PLATE II.

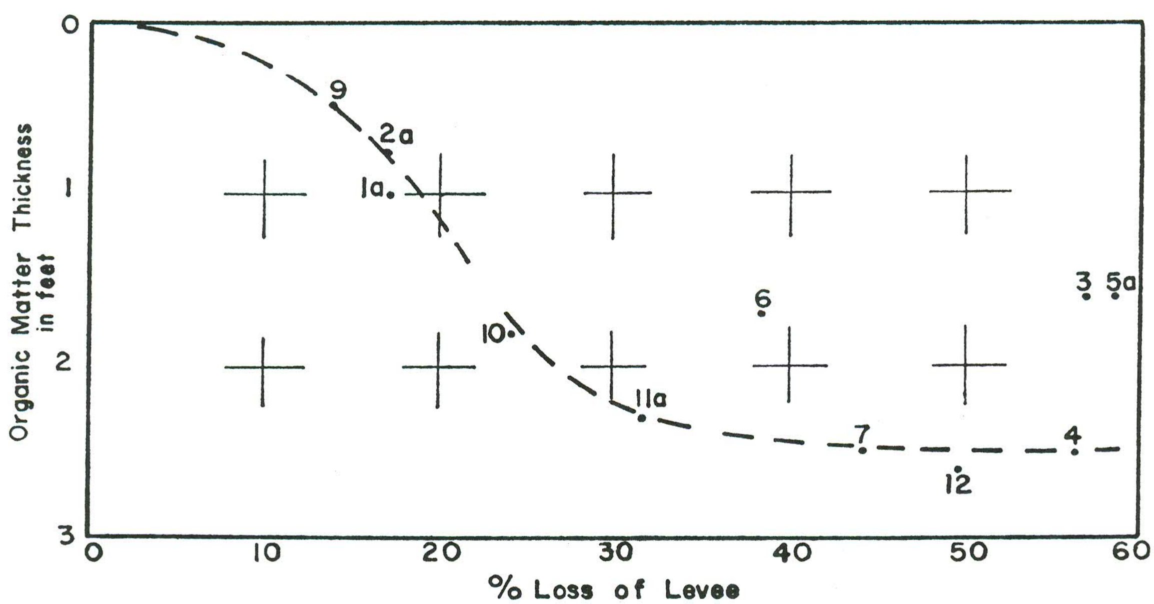
Rockefeller Refuge Levee Study

Levee Cross Section No. Ic

PLATE VI



a. Relationship between levee loss, organic matter thickness, and average moisture content of the undisturbed marsh from the surface to a depth of 8 feet.



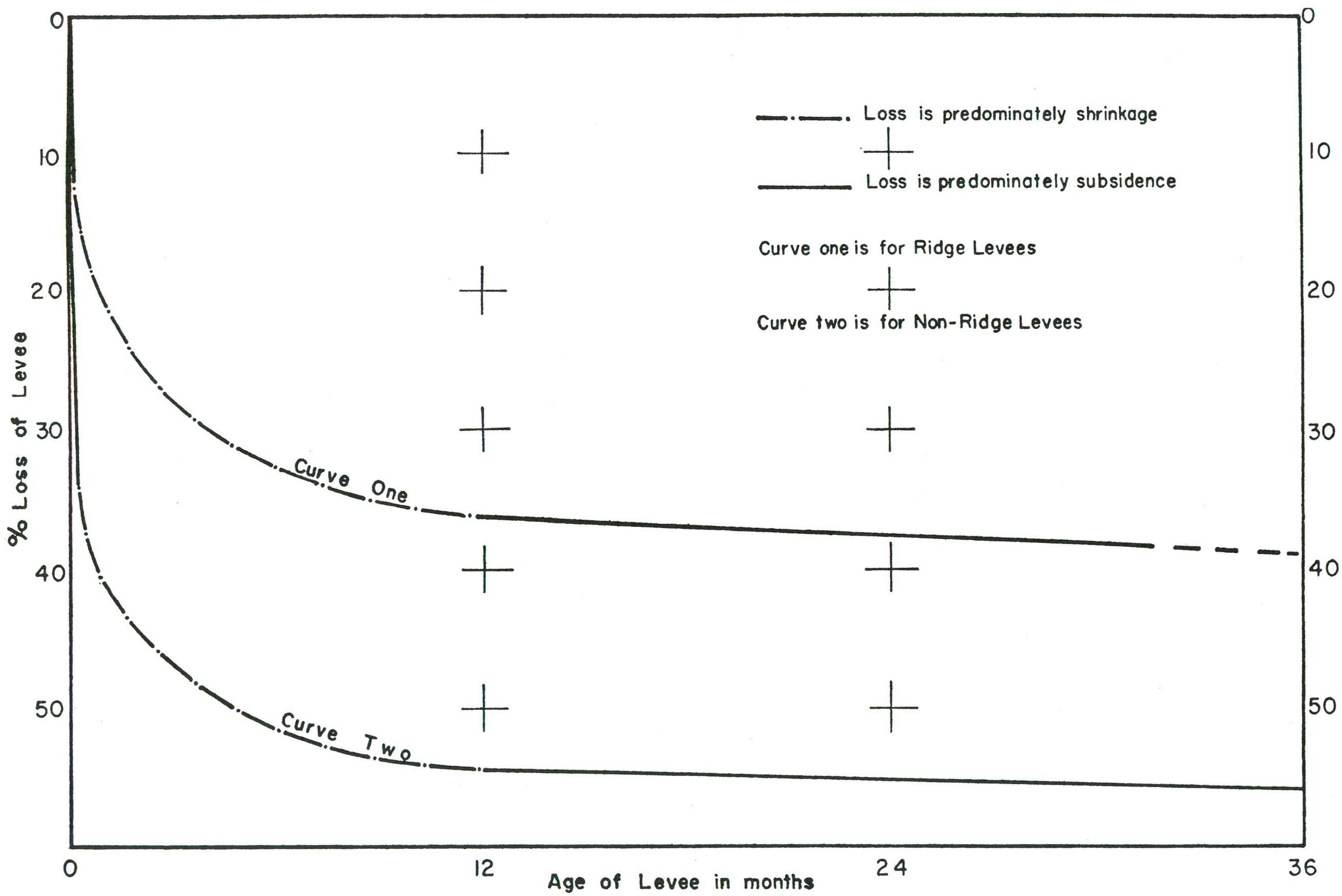
b. Relationship between levee loss and organic matter thickness.

Levee sections identified by numbers. See PLATE II for locations.

Rockefeller Refuge Levee St

Levee Loss as Related t
Organic
Matter and Moisture Cont

PLATE VII



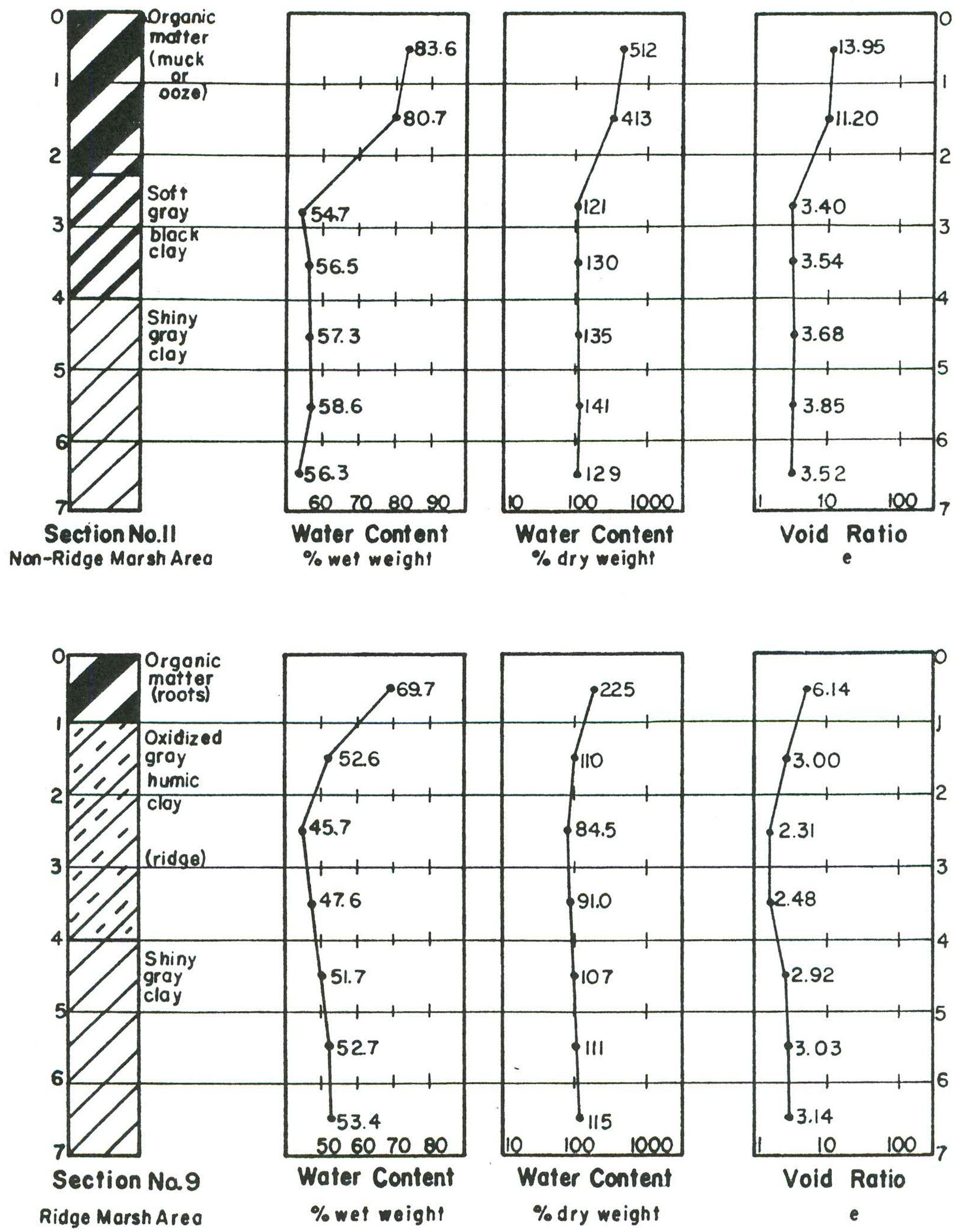
Predicted Loss of Levee Related to Time

Curves constructed from actual levee measurements

Rockefeller Refuge Levee Study

Levee Loss versus Time

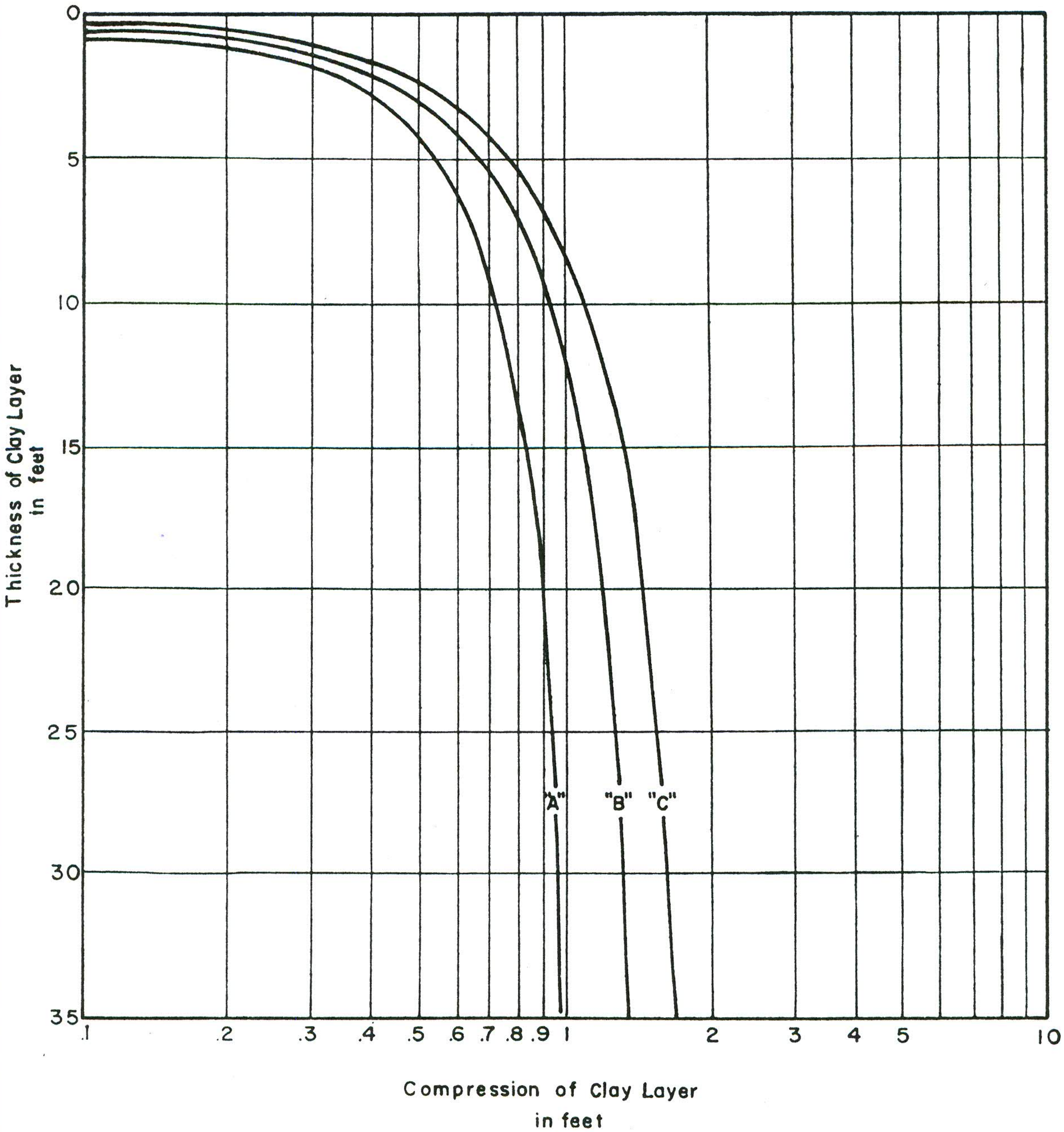
PLATE VIII



Rockefeller Reruge Levee Study

Test Borings of Marsh with relationships between water content and void ratio.

PLATE IX

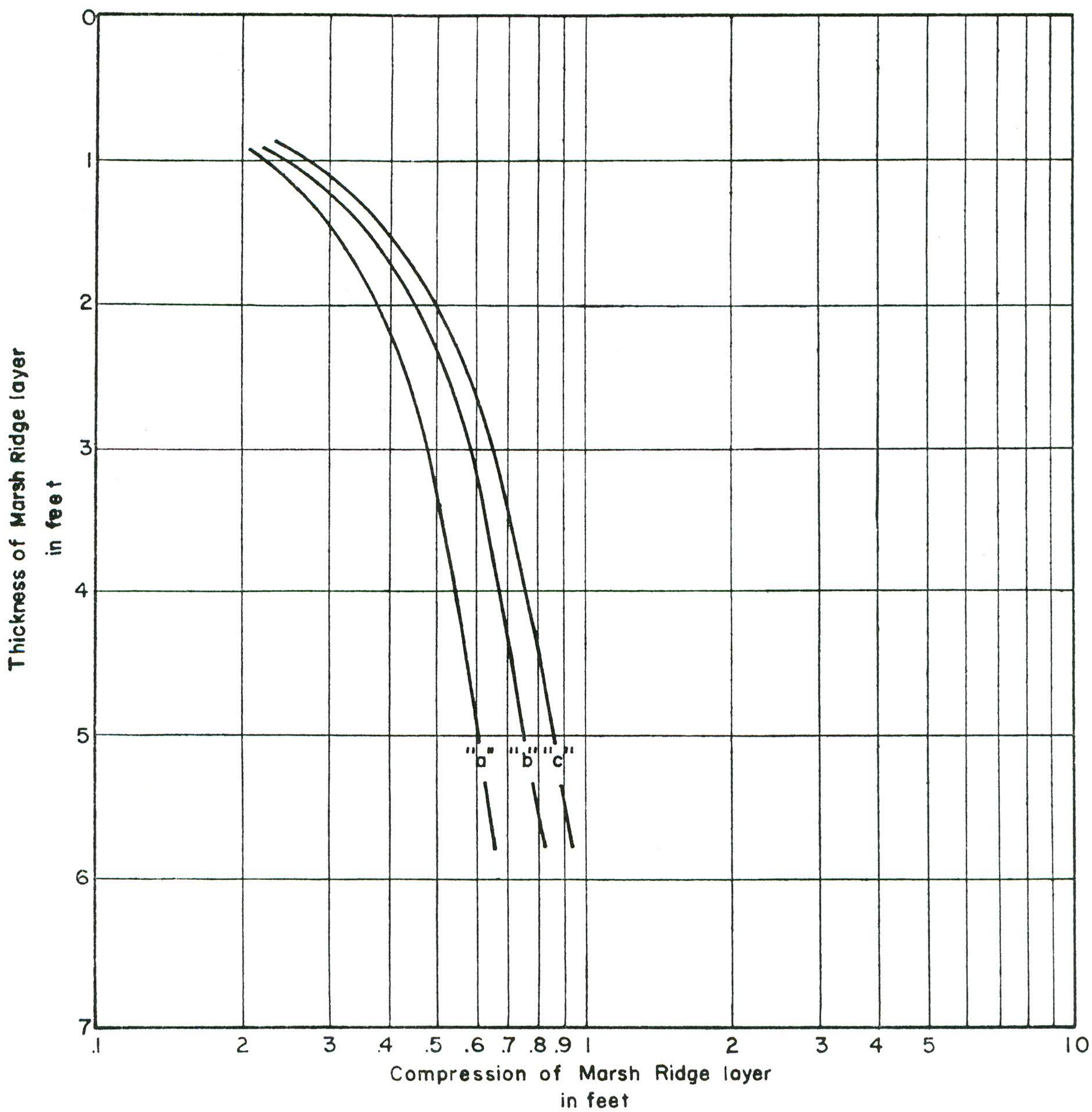


Predicted ultimate compression of clay layer as related to the thickness of the clay layer. Curve "A" is for a levee 4 feet high, Curve "B" is for a levee 6 feet high, Curve "C" is for a levee 8 feet high or one originally 6 feet high and later raised 2 feet. Curves constructed from results obtained by solving a compression formula for confined stratums.

Rockefeller Refuge Levee Study

Clay Compression Graph

PLATE X



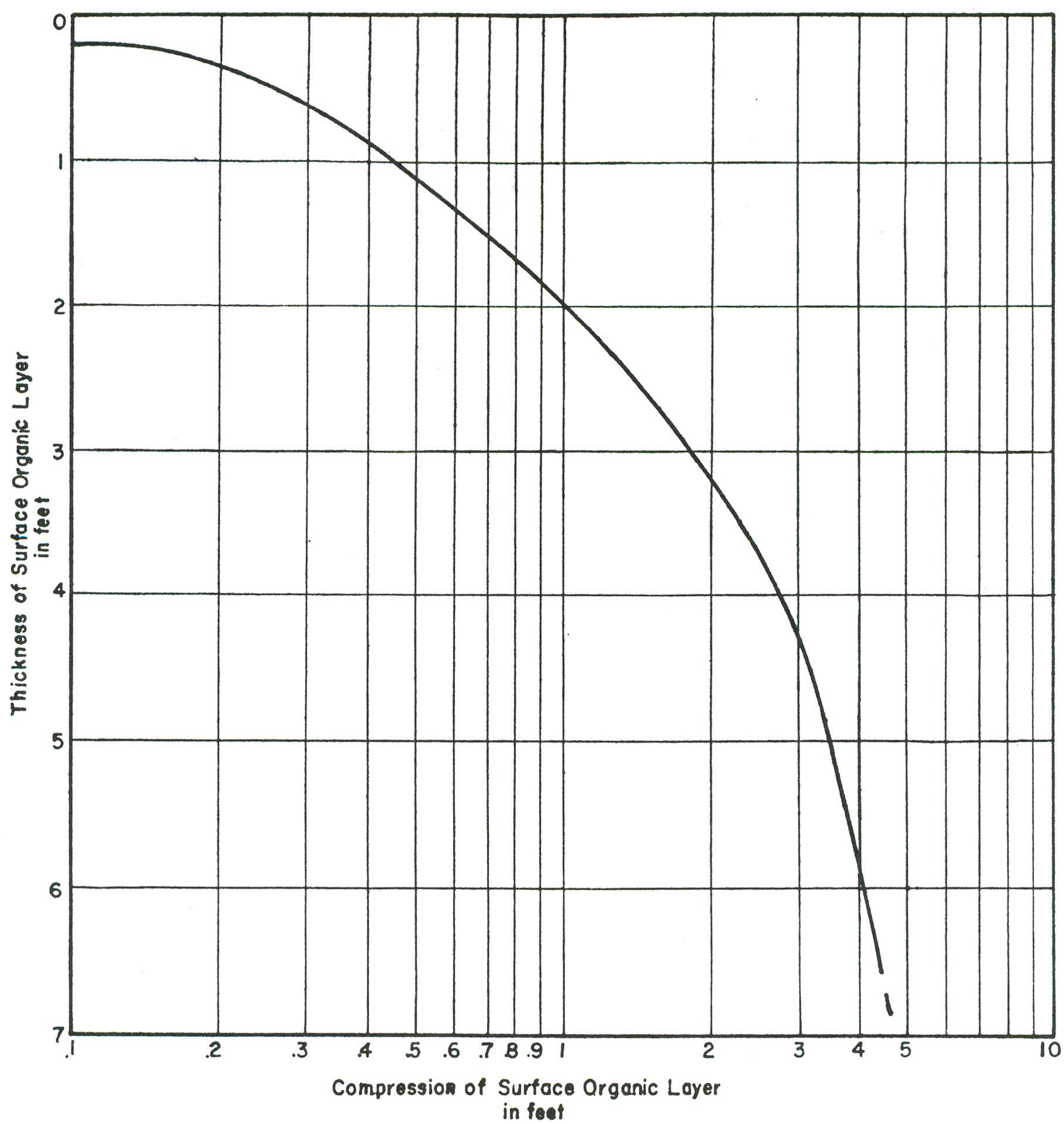
Predicted ultimate compression of marsh ridge layer as related to the original thickness of the marsh ridge layer. Curve "a" is for a levee 4 feet high, curve "b" is for a levee 6 feet high, curve "c" is for a levee 8 feet high or one originally 6 feet high and later raised 2 feet. Curves constructed from the results derived by solving a compression formula for confined stratums.

Rockefeller Refuge Levee Study

Marsh Ridge

Compression Graph

PLATE XI



Predicted compression of surface organic layer as related to the layer's initial thickness. Curve constructed from data obtained through measured levee sections.

Rockefeller Refuge Levee Study

Compression of Surface Organic Layer

PLATE XII